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Robonaut Provides Hands-On Assistance in Space

- **Humanoid robot can perform many astronaut tasks outside the spacecraft and during planetary exploration**
- **Handles standard tools and interfaces with spacecraft systems**

NASA astronauts not only endure long periods of zero-gravity conditions, but also face the dangerous challenges of operating in the hostile environment of space while performing maintenance and construction outside of their spacecraft, whether it be on the International Space Station today or on a Mars exploration mission in the future. For this reason, the CICT Program's Intelligent Systems (IS) Project, in collaboration with the Defense Advanced Research Projects Agency (DARPA), is funding development of Robonaut, a humanoid robot designed to perform many of these tasks for the astronauts. The robot is being developed at NASA Johnson Space Center's Robotic Systems Technology Branch.

Robotic builders and explorers

Robert Morris, manager of the IS Project's Automated Reasoning subproject, says, "Our researchers are developing sophisticated computational methods for robotic explorers, including automated reasoning and opportunistic or cooperative decision making. Advanced versions of humanoid robots like Robonaut," says Morris, "will be crucial to the safe construction and maintenance of astronaut habitats on the Moon and Mars, and for exploring unknown terrain. Today, Robert Ambrose and his colleagues are preparing Robonaut to be able to assist astronauts on the International Space Station or, in the future, on a planetary surface. That experience will provide valuable knowledge as we prepare to extend our presence further into the solar system and beyond."

A new class of robots

Robert Ambrose, principal investigator for Robonaut at NASA Johnson Space Center, says, "Only a few prototypes of humanoid robots exist today, but they are evolving rapidly. Most of today's humanoids are designed for entertainment, but Robonaut is the first tool-using robot, designed to do many of the tasks that human astronauts do. Our goal is to achieve human-like motion, intelligence, and communication. Initially, we imparted these skills to Robonaut via teleoperation, in which a remotely located human being controlled the system using

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Left: Robonaut is a space-capable, dexterous, humanoid robot designed to assist astronauts in performing certain tasks on space exploration missions. Right: Two Robonauts assist astronaut Nancy Currie in assembling an aluminum truss structure.

Technology Spotlight

Technology

Robonaut—a space-capable, dexterous, humanoid robot

Function

Assist the astronauts in their extra-vehicular activity (EVA) in space and during planetary exploration, as well as in rapid-response capacities

Relevant Missions

- Exploration missions
- International Space Station
- Space Shuttle

Applications

- On-orbit EVAs
- External habitat system maintenance
- Geological exploration and materials processing

Features

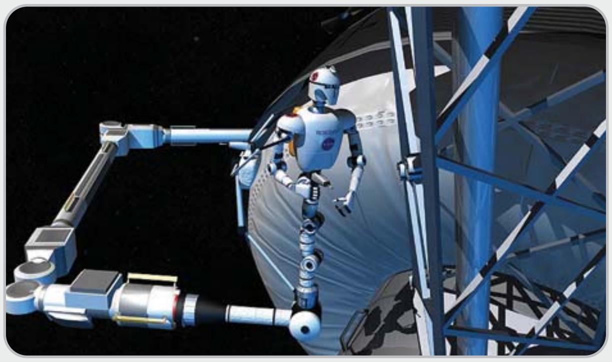
- Dexterous manipulation
- Short-term memory, haptic object identification, reflexive grabbing
- Distributed control (human teleoperation, shared control, and autonomy)

Benefits

- Reduce task load of astronauts and limit their exposure to potential in-space hazards
- Assist in building infrastructures, and serve as caretakers for the habitat before people arrive on a planet or moon, while they are there, and after they leave

Contacts

- Robert.O.Ambrose@nasa.gov
- Robert.A.Morris-Khatib@nasa.gov



Robonaut's body shell, made of carbon fiber and padded with Kevlar® and Teflon®, forms an impact-resistant defense against inadvertent contact with space debris when performing maintenance and construction outside of a spacecraft.

virtual reality gear. However, we continue to develop new software and sensors to enable shared control and, ultimately, autonomy."

Hands-on assistance

Robonaut has a waist with three degrees of freedom, a neck with two degrees of freedom, and a head with multiple stereo camera sets, as well as peripheral-vision cameras. It has two arms, each with seven degrees of freedom (shoulder, elbow, and wrist), and two dexterous five-finger hands. Each arm is also equipped with 150 sensors for performing complex tasks such as grasping a torque tool or making electrical connections. Robonaut's hands are similar to human hands in their dexterity and capabilities. Designed to handle the astronauts' tools, Robonaut's limbs can generate 20 pounds of force and 30 inch-pounds of torque needed to remove and install EVA orbital replacement units. Robonaut's body shell is made of carbon fiber and padded with Kevlar® and Teflon®, forming an impact-resistant defense against inadvertent contact with space debris.

Teleoperation using "telepresence"

"Robonaut's primary mode of control is an immersive version of teleoperation that we call 'telepresence,'" says Ambrose. Wearing virtual reality gear, the human operator is immersed in Robonaut's environment where he or she can intuitively control the robot's perception and maneuvers using head or limb motion. The teleoperator enables Robonaut to perform many human tasks that would be difficult to do autonomously, such as tie a cord into a knot or thread a nut onto a bolt. Other tasks, however, are candidates for shared control, or even autonomy on the part of Robonaut.

Sharing control

Astronauts can significantly reduce their workload by sharing control of some low-level skills and functions with Robonaut. Ron Diftler, deputy principal investigator for Robonaut, says, "To provide a more direct 'feel' to the teleoperator, we are beginning to use force feedback devices that pass forces directly back to the teleoperator. However, sometimes it's better to let Robonaut manage some of its forces locally. Therefore, we have built in 'compliance skills' that enable Robonaut to internally monitor and moderate the force it is applying. By keeping the forces at the appropriate level during operations, these compliance skills protect Robonaut and reduce the human operator's workload."

The team has also developed a set of software hand "primitives" for Robonaut, in order to simplify the human operator's hand motions in making specific grasps, such as pinch, tether, spherical, splint, and drill. These primitives enable the operator to use only a few human joints to control all 12 of Robonaut's hand joints. For example, the drill primitive freezes the command to all of Robonaut's fingers except the trigger finger, in order to operate a cordless drill.

Autonomy

Ambrose and his colleagues continue to develop Robonaut's autonomy as well. William Bluethmann, lead software systems engineer for Robonaut, says, "Robots such as planetary rovers have had some autonomy, including limited planning and navigational skills. Autonomy for humanoids, however, is still in its infancy because of the complexity of emulating a human. We have begun by developing base-level behaviors, such as coordinating hand and eye movements, coordinating multiple arm movements, and developing infantile grasp reflexes, something a baby acquires in its first year.

"In addition," says Bluethmann, "we are developing novel approaches to learning, such as extracting key features from the human operator's execution of a task and incorporating them in Robonaut's autonomous skill set. In the future, we could potentially extract these features in ground tests and then uplink them to Robonauts already in space, expanding their abilities."

So far, the team has developed a visual cortex and short-term memory for Robonaut to track and remember the location of tools and other objects. They've also installed a "grab reflex" in Robonaut's cerebellum that commands its fingers to close when its tactile glove senses contact with the object. Robonaut's cerebellum also contains an automated function for tactilely exploring an object or surface without visual support, to estimate its location and position for gripping.

"Robonaut continues to evolve," says Ambrose. "We continue to develop new sensors and algorithms to expand its capabilities and increase its options for augmenting human activity in space. Eventually, we expect Robonaut to be a trusted partner to astronauts on future NASA missions."

—Larry Laufenberg

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NASA CICT Program Office
Ames Research Center
650.604.2494

Program Manager
Butler Hine

Deputy Program Manager
Bill Van Dalsem

Infusion Editor
Larry Laufenberg
llaufenberg@mail.arc.nasa.gov

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